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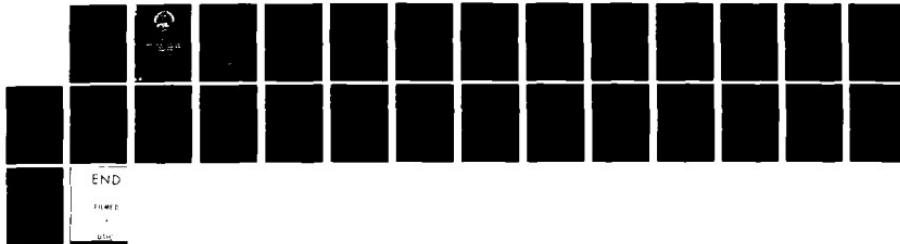
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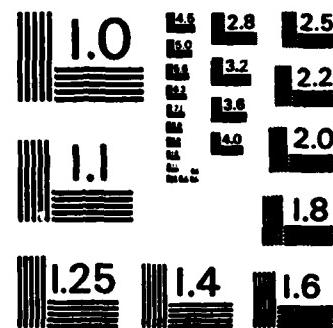
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Technical Memorandum 81-5

OBSERVATIONS ON A PLUG OF OLD SEA ICE IN THE
ENTRANCE TO NANSEN SOUND, ELLESmere ISLAND

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March 1981



Approved by:

A handwritten signature in black ink, appearing to read "H. Z. M".

Chief DREP

RESEARCH AND DEVELOPMENT BRANCH
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CANADA

ABSTRACT

A plug of multi-year sea ice lies in the entrance to Nansen Sound between Ellesmere and Axel Heiberg Islands. We discuss the history of the plug, give the results of observations made in 1980 and show that the plug is made up of sea ice of different ages and that it is still increasing in area. The present thickness of the ice in the oldest part of the plug averages about 6 metres.



A

INTRODUCTION

Along the northwest margin of the Queen Elizabeth Islands (Figure 1) most of the sounds and inlets north of 81°N to Ward Hunt Island are blocked by plugs of multi-year sea ice. These formations apparently grow from annual ice which becomes trapped by the conformation of the coastline or by offlying islands and shoals. The thickness of the ice varies from about three to ten metres. The ice plugs may increase in area by accretion of new strips of sea-ice or they may break up in part or completely after a lifetime which appears to be several decades long. Their surfaces become irregular with rounded relief typical of an ablation surface. Ridge and valley topography may form parallel to the prevailing winds and may reach several metres in height (Hattersley-Smith, 1957). Along the outer margin, heavy pressure ridges form in the annual sea-ice.

The plugs are of interest for two main reasons. When they eventually break up they spill very heavy floes into the normal circulation of the Beaufort Sea gyre which are then carried into the regions where oil recovery is going on. Secondly, the plugs provide a stable platform for the investigation of the growth of multi-year ice and for the establishment of long-term instrument packages for oceanographic research.

Two of the plugs have received attention in the past (Figure 2), that in Sverdrup Channel (Serson, 1974) and the one in the entrance to Nansen Sound (Serson, 1972).

SVERDRUP CHANNEL ICE PLUG

Typical fixed plug-ice was observed in the Sverdrup Channel in 1900 by Sverdrup (1904), and in 1914 by Stefanssen (1922). The strait was crossed by Cook in 1908 and by Krueger a few weeks before his disappearance in 1930. In more recent times it has been traversed by a number of parties from government, a private group and an oil rig camp move. Meighen Island has been occupied almost every summer since 1959 by glaciological parties. It seems that for at least 80 years there have been only minor changes to the extent of the plug, such as the loss of a strip along the northwest face which disappeared sometime between 1959 and 1970 and which was replaced before 1973 (Serson, 1974). The ice of the plug is generally more than 5 m

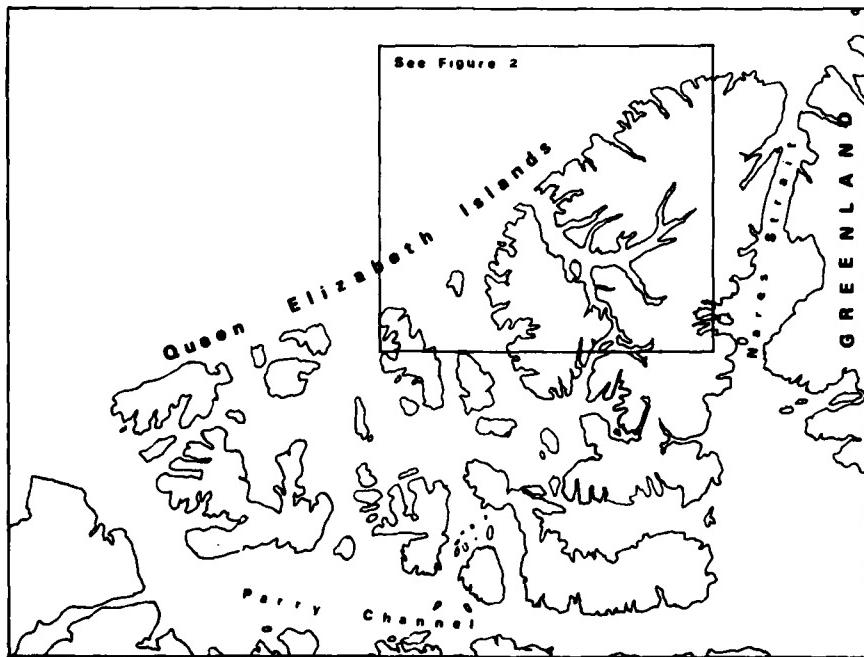


Figure 1. The Canadian Archipelago, Queen Elizabeth Islands.

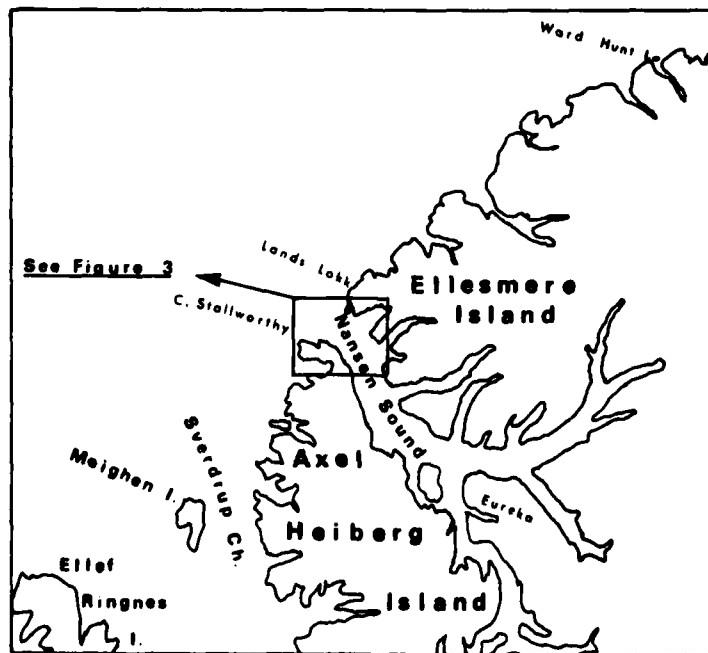


Figure 2. Map of northwest coast of Ellesmere Island showing the locations of Sverdrup Channel and Nansen Sound.

thick and is sufficient to trap a layer of fresh water on the surface of those inlets whose mouth it blocks. There is no indication of tidal cracking, hinging or flooding along the shorelines.

NANSEN SOUND ICE PLUG

The plug in Nansen Sound has had a more varied history. It was crossed by Peary in 1906, Cook in 1908, MacMillan in 1914 and by Krueger in 1930. However, in 1932, Stallworthy (Anon. 1934) was prevented from crossing from Axel Heiberg Island to Lands Lakk Point because of a "bad surface consisting of new pressure ice" Subsequently, the plug re-formed and between 1964 and 1971 visits were made to it by parties from the Defence Research Board.

In the fall of 1971, after a presumed lifetime of 40 years, almost all of the plug broke up. A surface traverse in May 1972 indicated that a 14 km wide portion from the southeastern part of the plug was lying off the mouth of Otto Fiord, bridging Nansen Sound. Much of the remainder of the plug had broken up allowing icebergs from Otto Fiord to migrate along the Axel Heiberg coast to Cape Stallworthy. Along the south west side of the large Fjeldholmen Island the ice was rafted to a height of 30 m. The ice remaining in the mouth of Nansen Sound consisted of floes up to 3 km in diameter of old "plug ice" surrounded by broken ice. Photographs of the plug taken in 1972 indicated that many blocks of ice were forced up in a random pattern by the pressure; there was no indication of linear pressure ridging.

An overflight in May 1973 showed icebergs at Cape Thomas Hubbard and along the Axel Heiberg coast. The boundary between the Arctic Ocean pack and the Nansen Sound ice extended from Cape Stallworthy north east to Krueger Island. When the plug was revisited in May 1976 the surface had reverted to a random pattern of hummocks surrounded by frozen fresh water ponds. Since 1972 the plug has re-formed and appears to be still increasing in area. The observations reported here were made in March-April and September-October 1980.

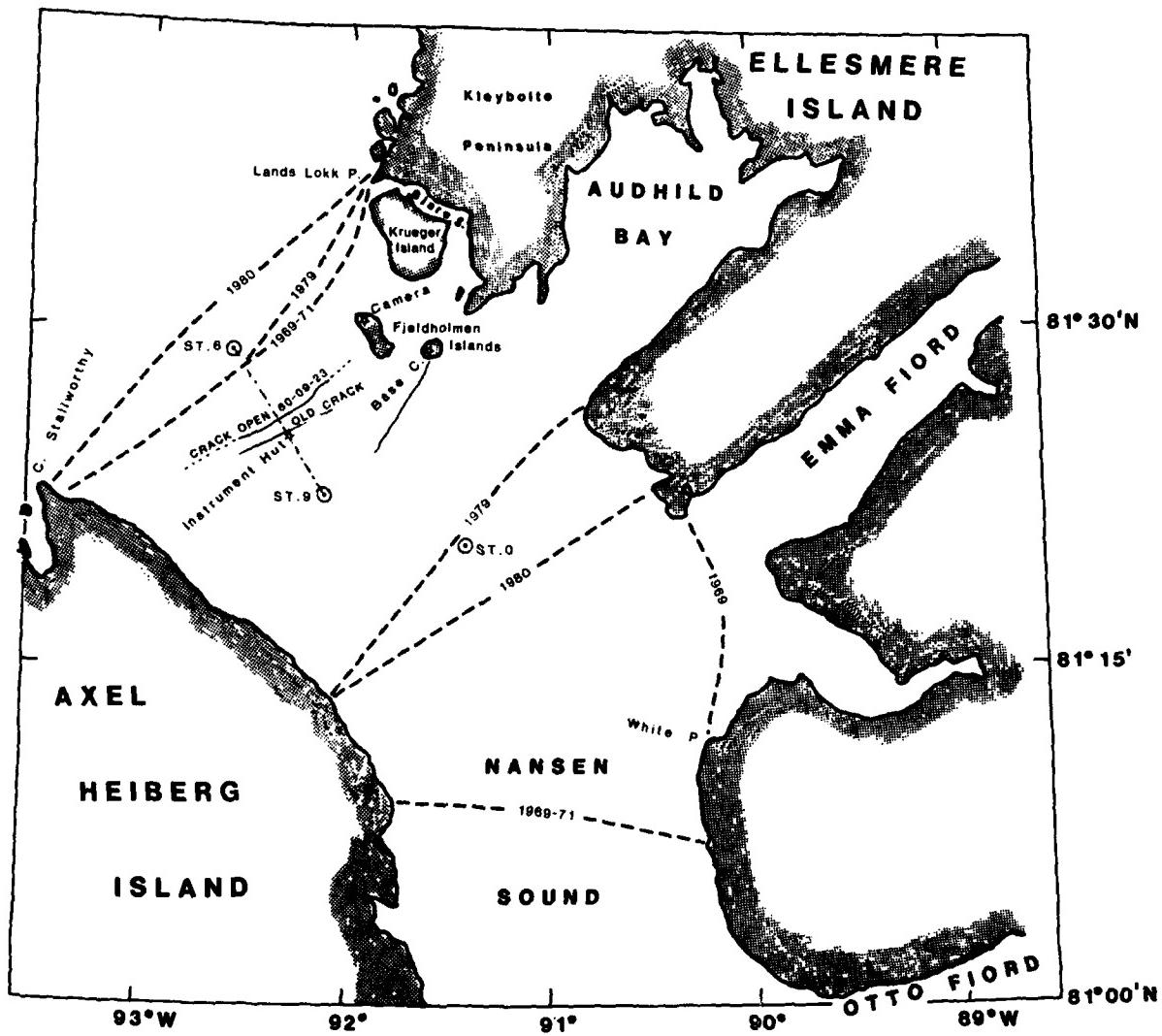


Figure 3. Map of the northern end of Nansen Sound showing the approximate limits of the fixed ice plug in different years. Ice thickness measurements were made on the line joining Station 6 to Station 9 and at Station 0.

OBSERVATION IN NANSEN SOUND, 1980

Extent of the Ice-Plug

Figure 3 indicates the approximate boundaries of the plug in 1969 and 1971 and in 1979 and 1980. Before the breakup of 1971, the plug extended 53 km in a northwest-to-southeast direction, the boundaries shown being taken from an air reconnaissance in 1969 and from two sections made by Serson (1972). By 1979 an air reconnaissance showed that the plug had re-formed and now extended for about 26 km, covering only half of the area of the 1971 plug. In March 1980 we found that the plug had again increased in size by the accretion of a strip of two-year old ice at each end. The seaward end of the plug was thus even further to the northwest than was that of the fully developed plug of 1971, while the southeast end still fell far short of its maximum extent.

Surface Relief of the Plug-Ice

Between 1964 and 1971 the surface relief was fully developed as an old ablation surface. The roughness increased from northeast to southwest across Nansen Sound, with typical hummocks being 1.5 m high on the northeast side and 3 m high on the southwest side. This was due to the extra snowfall which occurs in the lee of the high ground on the northeast side of the sound; the heavy snow cover reduces the extent of the annual ablation in that area. In March 1980 the surface relief was much less, particularly on the northeast side of the sound where the ice surface was smoothed by packed snow extending 2 or 3 km from the shore. Further out the hummocks were generally about 1 or 2 m high. In October, although the surface was partly obscured by the first fall of fluffy snow, we found that the hummocks varied from about 1 to 1.5 m in the northeast third of the channel to about 1.5 to 2.5 m in the central and southwest areas. The morphology indicated that some of the hummocks which have vertical faces 0.5 to 1 m in height were the ablated remains of pressure ridges. Over the newer ice, which had been added to the

northwest face of the plug since the 1979 flight, the relief was less pronounced and the surface appeared to be typical of normal two-year ice. An ablated pressure ridge some 3 m high, which marked the northern section of the junction between this ice and the older part of the plug, ran from the southwest corner of Krueger Island in a southwest direction for 2 or 3 km. Several refrozen leads and cracks were observed, one of which was approximately in the same position as a lead observed in 1969 (Figure 4) while another ran across the channel through the newer ice. A time lapse camera record later showed that the latter had open water in it on 20 and 22 September; on 26 September the lead was covered by 30 cm of ice.

Thickness of the Ice-Plug

In 1968, the ice that was 400 m in from the seaward edge of the plug was 10 m thick, while in 1970 and 1971 the measurements indicated an average thickness for the main part of the plug of 4 m, (Serson, 1972). Only in the southern portion, where the ice cover was typical two year ice, was the ice thickness less than 3 metres. In March 1980, one hole drilled in the older part of the plug gave a thickness of 6.6 m (Table 1), with the average of 5 readings being 5.3 m. A hole in the newer southerly extension of the plug, at 81°21'N 91°25'W (Station 0 in Table 1), had only 3.0 m of ice in March 1980. In September 1980 we made ice thickness measurements on a line of bearing 147° - 327° through the position of the instrument hut (Ice Hut) located near Station 1 at 81°26.5'N 92°16.5'W. The positions of the measurements are shown in Figure 4. The line extends from Station 9 in the middle of the older section of the plug in a northwest direction to Station 6 near the outer edge of the plug.

The measurements in the vicinity of the Ice Hut are shown on a larger scale in Figure 5. To avoid unconscious bias in the selection of the exact location of drilling points, most of the station positions were set by

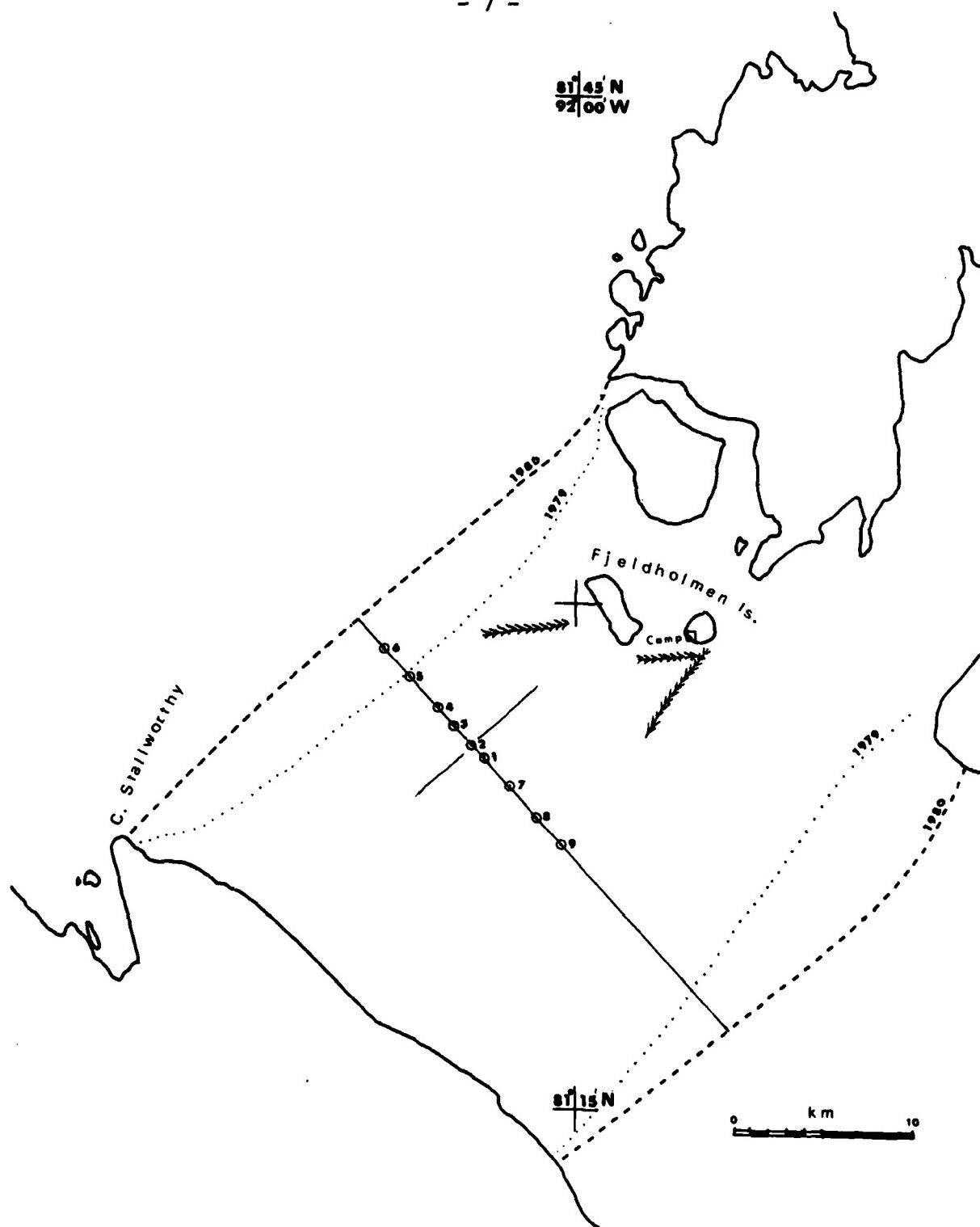


Figure 4. Map showing the positions (Stations 1 to 9) at which ice thickness measurements were made. Prominent pressure lines are shown hatched. The line at Station 2 shows the observed extent of the lead which was open on 25 September 1980.

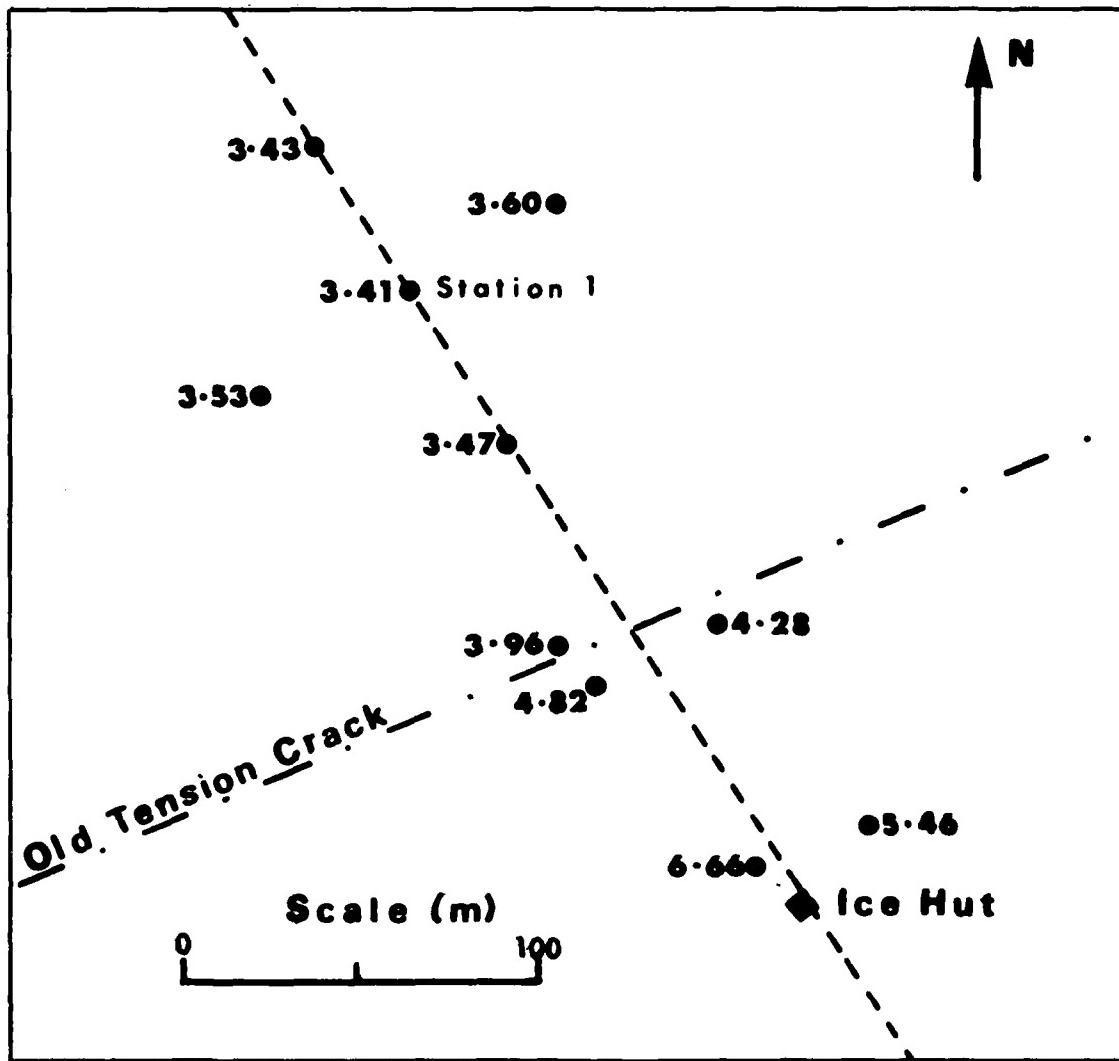


Figure 5. Ice thickness, in metres, recorded at ten locations in the vicinity of the Ice Hut.

using a 200 m tape to measure the distance, the first hole being drilled exactly at the end of the tape. Other holes were located by taping exact distances from the main station hole.

The ice thicknesses are given in Table 1 and Figure 5, while the ice thickness profile is shown in Figure 6. The thickness appears to be bi-modal along this line with an outer section of about 3.5 m and an inner section, from the Ice Hut onwards, which has a mean thickness of about 5 m. The only two anomalous thicknesses are the 8.65 m recorded at Station 6, where the hole appeared to be sited on top of an ablated ridge, and the 0.3 m recorded in Station 2 which was in the centre of a recently refrozen lead. Between the Ice Hut and Station 1, which is about 200 m northwest of the hut, lie the remains of an old tension crack and there was an abrupt change in thickness across this feature which is obvious in Table 1 and in Figures 5 and 6. The difference in ice thickness on the opposite sides of this crack near the Ice Hut indicates that it marks the junction between the oldest ice in the plug and a section which is some years younger.

The refrozen lead at Station 2 was about 20 m wide and was recognizable as such for several kilometres. It ran roughly at right angles to the axis of the channel. On later snowmobile journeys this lead was found to extend at least 5 km towards Krueger Island from Station 2. It was later identified with the open lead which was visible in the time-lapse camera film taken from the crest of big Fjeldholmen Island.

Temperature Profiles

On 11 April 1980, we installed a 10-thermocouple chain through the ice at the Ice Hut position. It was secured to a 4"x4" stake which had been set in the ice as a reference level for the hut itself. The junctions were secured to the stake at 1 m intervals with the uppermost sensor at the ice surface. Readings were made using a 10-position switch, a Keithley digital millivolt meter and an ice/water bath as a reference point. Two profiles are shown in Figure 7, the depths being taken relative to a fixed ablation mark

TABLE I

ICE THICKNESS MEASUREMENTS

STATION	DATE	HOLE NO.	ICE	SNOW	FREE	REMARKS
			THICKNESS (m)	THICKNESS (m)	BOARD (m)	
0	25 Mar	1	3.00	0.00	-	Refrozen melt pool on new ice on SE end of plug.
Ice Hut	22 Mar	1	3.90	-	0.10	On tension crack.
	21 Mar	2	4.20	-	0.58	NE of tension crack.
	21 Mar	3	4.80	0.00	1.40	SE of tension crack 100 m NW of Ice Hut position.
	22 Mar	4	6.60	-	0.80	At current meter position.
	22 Mar	5	5.40	-	-	NE of Electronics Hut
1	26 Sep	1	3.41	0.01	0.03	200 m NW of electronics hut.
		2	3.43	0.01	0.16	
		3.	3.53	0.05	0.09	
		4	3.47	0.03	0.20	
		5	3.60	0.00	0.20	
2	26 Sep	1	0.30	0.01	0.02	On refrozen lead.
		2	3.00	0.01	0.25	25 m NW of lead.
		3	3.58	0.02	0.57	25 m SE of lead.
3	26 Sep	1	3.68	0.00	0.40	
		2	3.60	0.01	0.18	50 m NW of Hole 1.
		3	3.20	0.00	0.01	50 m SE of Hole 1.
4	26 Sep	1	3.59	0.01	0.11	
		2	3.66	0.10	0.12	50 m NW of Hole 1
		3	3.60	0.05	0.15	50 m SE of Hole 1.
5	29 Sep	1	4.35	0.00	0.42	50 m SE of Hole 2.
		2	4.33	0.19	0.19	
		3	3.49	0.16	0.00	50 m NW of Hole 2.
6	29 Sep	1	4.32	0.10	0.42	50 m SE of Hole 2.
		2	8.65	0.18	0.65	
7	30 Sep	1	5.57	0.10	0.86	
		2	4.81	0.00	0.66	50 m NW of Hole 1.
		3	5.42	0.05	1.05	50 m SE of Hole 1
8	30 Sep	1	5.54	0.00	0.80	
		2	4.36	0.10	0.74	50 m NW of Hole 1.
		3	5.49	0.08	0.68	50 m SE of Hole 1
9	30 Sep	1	5.74	0.12	0.80	
		2	4.62	0.00	0.64	50 m NW of Hole 1.
		3	4.47	0.05	0.58	50 m SE of Hole 1.

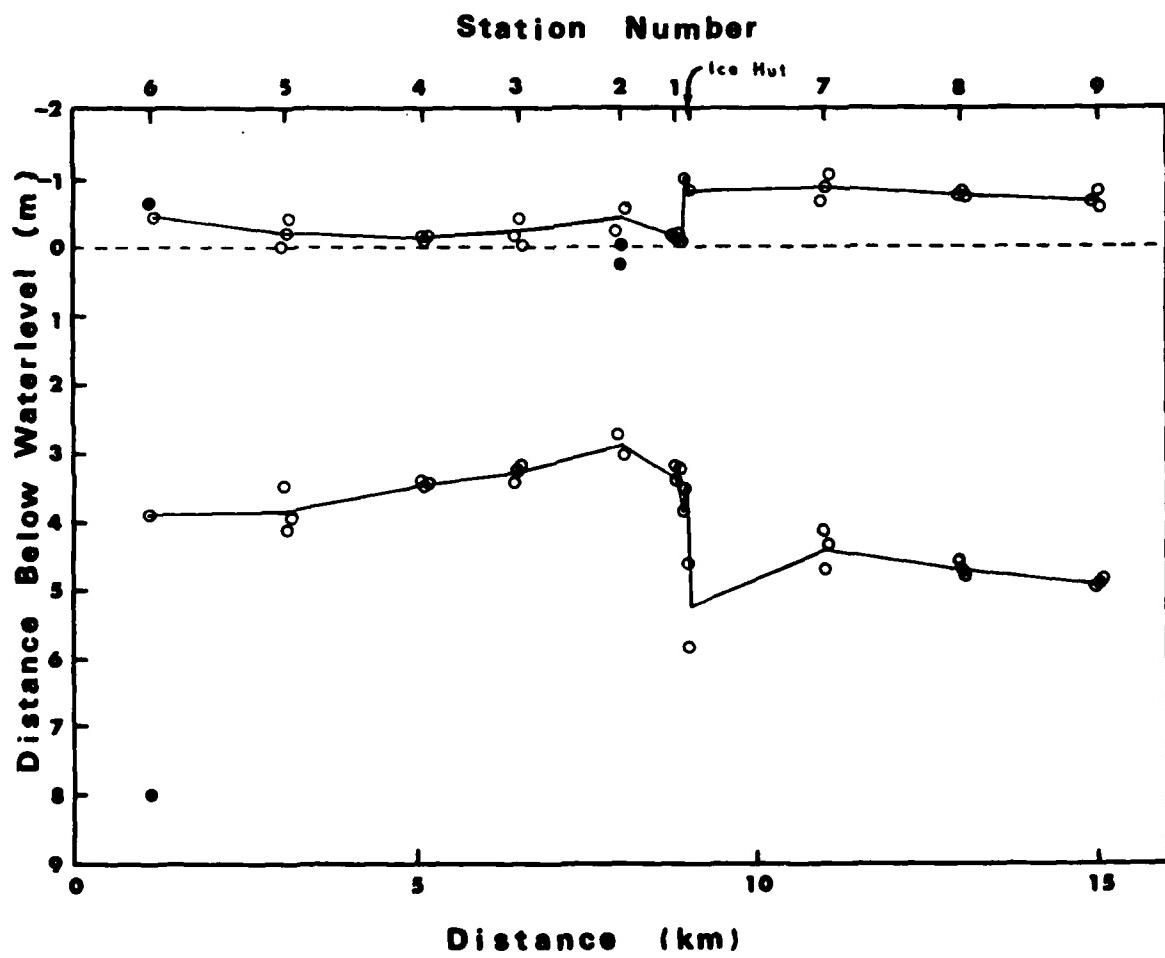


Figure 6. Profiles of the upper and lower surfaces of the ice along the section from Station 6 to Station 9. The solid lines are drawn through the average readings at each station; the individual readings being marked by the small circles. The abrupt change in ice thickness between Station 1 and the Ice Hut is clearly shown.

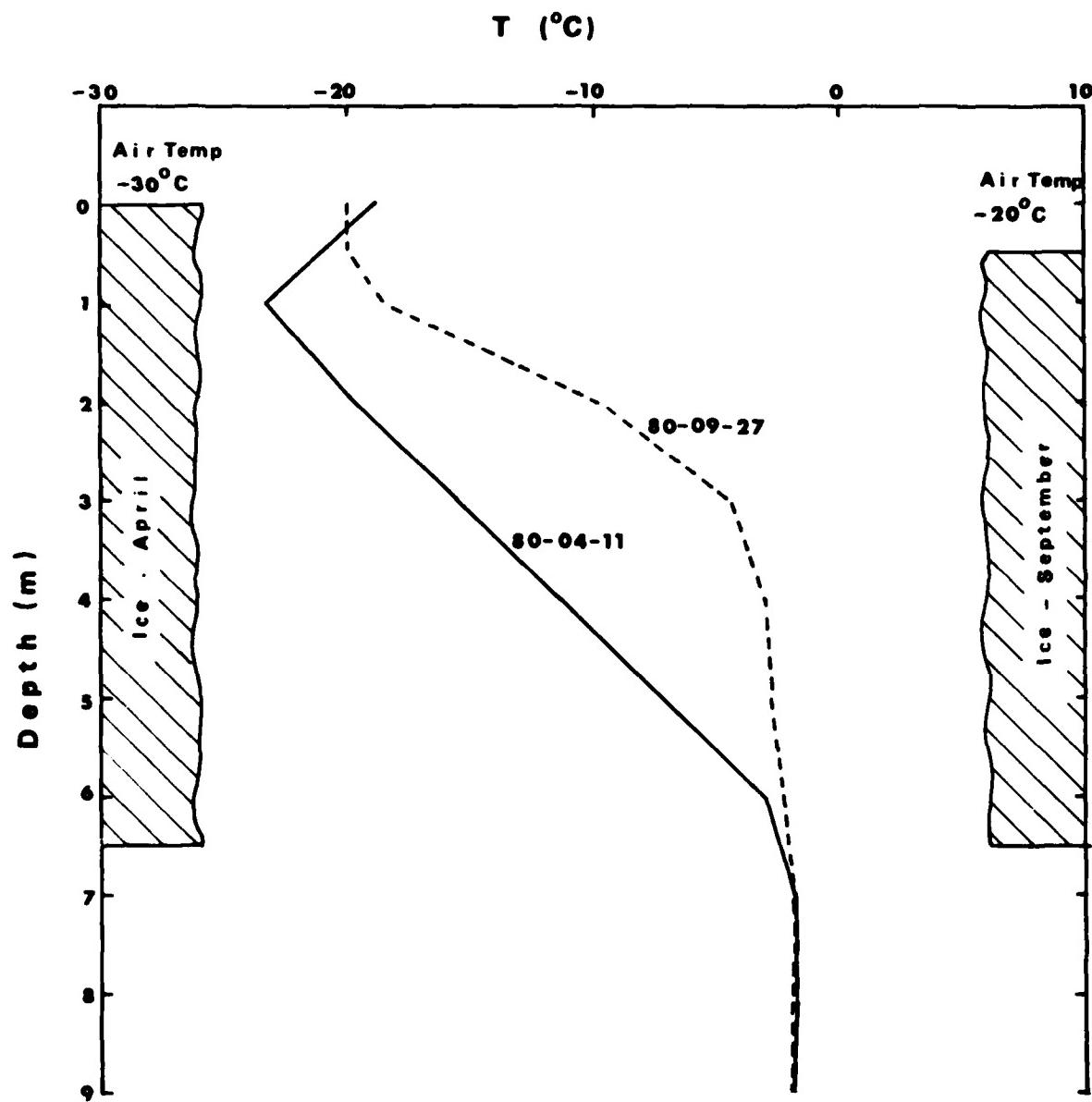


Figure 7. Temperature profiles through the ice near the Ice Hut measured with a chain of thermocouples at 1 m intervals in April and September 1980.

on the stake. The negative gradient in the upper metre of ice in the April profile is due to the increasing solar radiation, the constant gradient below that being the remains of the winter equilibrium. The 27 September profile has a surface temperature close to that in April, but the upper junction is now in air because of about 0.5 m ablation which occurred during the summer. While the upper surface has ablated 0.5 m, there has been less than that amount of accretion on the lower surface since the bottom two junctions are still in the water. During the winter of 1980/81 junction 8 should become frozen into the lower surface of the ice.

Bathymetry

There have been few previous soundings in this area, so we intended, travelling by snowmobile and sledge, to run a line of soundings out from the end of the plug towards the continental shelf break. A reconnaissance flight in early March, however, showed that the sea-ice surface along the west coasts of Axel Heiberg and Ellesmere Islands was so rough that travel on the ice was impossible. Twenty soundings were made, using a sounding wire and hand winch, and 18 of these were taken using a helicopter for transport. The 1980 soundings are shown as large dots in Figure 8 which shows all the available soundings in the area. The results indicate that there may be a comparatively shallow rise to about 260 m which extends across the mouth of Nansen Sound out to about 60 to 80 km before the water deepens again to the shelf break. The water over the rise is less than half as deep as that in the channel.

Time Lapse Photography

A time lapse camera began recording on 2 May 1980 and continued until 25 September. It was mounted on the northern peak of big Fjeldholmen Island at a height of 300 m and was oriented at 306° towards the northwest face of the ice plug. With a lapse time of 40 minutes between photographs,

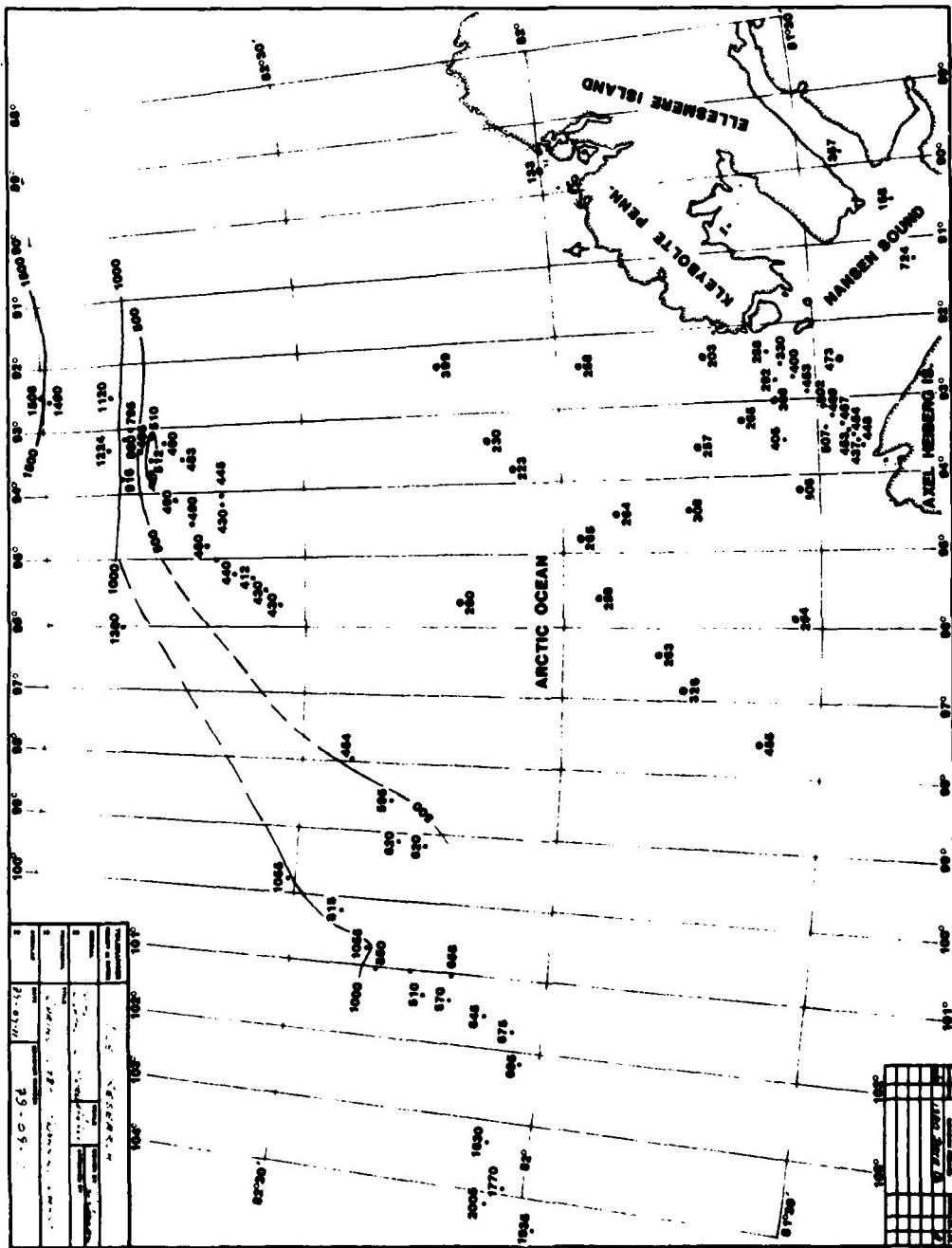


Figure 8. Copy of a plotting sheet showing all available soundings, in metres, near the mouth of Nansen Sound. The 1980 soundings are shown as large dots.

4236 frames were obtained, but mist or snow obscured the camera for all or most of the day on 78 days of the 124-day period; September being the worst month. Enough information was recorded to throw some light on the stability of the plug and the incidence of open leads and cracks. Details of the camera system are given in Appendix A.

Pile Stability Measurements

The Ice Hut is supported on four piles frozen into 2 m deep holes drilled in the plug ice during April 1980. A series of measurements was begun to determine any sinking or tilting of the hut caused by summer ablation or creep of the piles. The results to date are given in Appendix B.

DISCUSSION AND CONCLUSIONS

The observations indicate that the present ice plug in Nansen Sound began to form some time after 1972 and that it is still growing in extent and thickness. Some old ice, locked in by islands, is probably a remnant from the previous ice mass; that in Bjare Strait may well be among the oldest sea ice in existence. The main part of the plug originates when a section of the winter ice across the strait is not broken up by summer melting, wind or current; subsequent winter freezing makes it even less likely to move in following years. The ends of this fixed ice mass then behave as a shoreline, additional sections of "shorefast ice" adhering to it as wind and weather conditions dictate. In the absence of unusual phenomena, in about 1984 or 1985 the ice should approach an equilibrium thickness of five or six metres and may then rival in extent the plug of 1969.

Some of the ice plugs may remain in place for many years while others, like the Nansen Sound plug, are less securely held by the shoreline configuration and break out after a lifetime measured in decades. The reasons which trigger the breakup, such as occurred to the Nansen Sound plug in 1972, are not known. The tide cracks along the shore are small and do not

appear to be working, but we do know that tension cracks exist, probably maintained by temperature changes, which dissect the plug. There is also some indication that these cracks may mark the dividing line between ice of different ages and that they begin at points of stress with the land - for example the Fjeldholmen Islands. The other obvious factor is the wind stress. For example, time-lapse photographs show that at the time when the lead through Station 2 was open, the pack-ice had been driven some distance away from the northwest face of the plug. The wind at the camp on little Fjeldholmen Island at the time was from the northeast at about 10 kph but this is not very significant since the winds in the area are local and are strongly influenced by the land topography. We observed in September that over a period of 5 days the outer end of the plug beyond Station 4 was swept by a northeast wind (down the coastline) of 40 to 50 kph with a temperature of -28°C to -30°C , while the winds at the Ice Hut (Station 1) were light and the temperature was -20°C . The winds on the plug bear little resemblance to those recorded at the weather station at Eureka, about 180 km away, but it is clear that the normal summer storms are insufficient to break out the ice. We consider that such a breakout must be the result of exceptionally high winds (a '50 year storm') from the northeast, combined with light pack-ice conditions offshore and possibly with an extraneous event such as a tsunami.

The probability that the main part of the Nansen Sound plug will break out in any given year is therefore low and may on past evidence be assumed to be less than 1:10. The records seem to indicate that the Sverdrup Channel plug has a lifetime measured in decades. However, ice cores obtained in May 1973 did not sit on a greater accumulation of wind transported dust than cores from the ice in the Nansen Sound plug, and much less than from the old grounded ice between Perley Island and Meighen Island. Little is known about the plugs in the more northerly inlets since early travellers tended to travel on the smoother ice just inside the first pressure ridge and not to penetrate the mouths of the fiords. There is frequently a progression in ice types as one moves towards the sea, from ice cap to glacier to ice shelf to ice plug to annual ice and to heavy ice pile-up on shoals offshore. In

general it is safe to say that ice plug formations provide stable instrument locations with low probability of breaking out before the experiment is finished.

Other problems connected with the ice plugs are yet to be investigated. Serson (unpublished data, 1981) for example, has recorded a great deal of rock and other material on the surface of the plug ice, particularly north of Nansen Sound, including blocks massing thousands of kilograms. The transport of this material at breakup may be of considerable importance in sediment and bottom studies. We also suggest that the plugs constitute a natural barrier to the movement of most marine mammals since the ice is thick, the cracks are few, and the tide cracks unusable.

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APPENDIX A

TIME-LAPSE PHOTOGRAPHY

The following are the specifications for the equipment used to obtain time-lapse photography of the northwest portion of the Nansen Sound ice-plug. The film records are available at DREP.

Camera: W. Vintren Ltd., 16 mm camera, Scientific.

Location: On the highest point of the northern peak of big Fjeldholmen Island
Lat. 81°30.5'N Long. 92°05'W.

Elevation: 300 m.

Orientation: Towards northwest face of the plug (306°).

Program Unit: Quartz crystal controlled.

Lapse Time: 40 minutes. Timer constructed in-house.

Lens: f3.5 x 25 mm. Field of view: 40° x 30°. Aperture: f16.

Shutter speed: 1/75 second.

Filter: Polarizing filter, factor x2.

Film: Kodak "Video News" 5239, 7239, E. I. 160. 16 mm. Magazine: 200 feet.

Power Source: Eveready Type 520 alkaline lantern batteries.

Start: 2035Z 2 May 1980, Frame 1.

Stop: 1620 25 September 1980, Frame: 4263.

Frame Count Ratio: Because of adaptions to the camera feed, the frame counter/time in the camera did not coincide exactly with the actual number of frames exposed. The ratio was 1.0544 i.e. 36 frames = 1 day = 34.142 counts.

Preparation: The camera was completely disassembled, cleaned and lubricated with instrument oil Type 3GP33SC (Mil. Spec. Mil-L-7870A). The camera and batteries were 'cold soaked' in an environmental chamber at -50°C and then tested with the program unit at -30° C.

Timing: An independent 24-hour clock was in the field of view. It ran from 2 May to 27 May when it failed because of blowing snow penetrating the case. Up to failure, this clock agreed with the crystal controlled program unit. A time check based on the time of recovery and the frame count showed that the maximum timing error was \pm 10 minutes.

Results. The camera was not fitted with automatic aperture control but this did not affect the usefulness of the exposures until 20 September, when two frames, at about local midnight, were too underexposed to show the ice conditions. The number of underexposed frames increased daily to eight on 25 September.

Fog, low cloud and snow or ice obscuring the filter reduced the number of useful pictures to 36% of the number of exposures; the longest blank period being from 30 August to 19 September. Open water first appeared on 28 August at the north west face of the plug and developed into a wide lead which extended right across the mouth of Nansen Sound. The first sign of movement in the plug itself was at 0440(Z) 22 September when a lead opened to the NW of the refrozen crack at the Ice Hut station. By 0520(Z) the crack near the Ice Hut had also opened and the piece of the ice plug between the two leads was moving north by 1440(Z). The leads were still open at 2040Z when snow obscured the camera but when the camera cleared on 25 September both leads were re-frozen and snow covered. On 26 September the outer lead had 30 cm of ice on the surface.

APPENDIX B

INSTRUMENT HUT

An instrument hut, which was supported by piles set into holes bored in the ice, was established on the Nansen Sound ice-plug. We began a series of measurements to determine the stability of such pile-supported buildings as successive summer ablation seasons remove the surface ice around them.

The four load-bearing piles which supported the 8-foot square hut, were 10 feet long and approximately 15 cm x 15 cm (3 nominal 6" x 2" planks laminated) in cross section. The piles were frozen into 20-cm holes drilled 2 m into the ice. The tops of the piles were bound together by horizontal beams which supported the hut. The total mass of the hut and contents was approximately 2600 kg, or 650 kg on each pile. A fifth pile, made from a 4" X 4" post, was mounted in a hole drilled right through the ice to act as an unloaded reference and also to form a support for a thermocouple chain. Reference plates were fixed to all five piles and the height of each of the marks on the loaded piles with reference to the unloaded pile were measured using a hydrostatic level. This level consisted of a 4-m length of flexible polyethylene tubing with a length of glass tubing in each end. Diesel fuel was used as the filler since it was readily available and clearly visible in the tube. We used a steel tape to measure differences in level and consider that the vertical distances given in Table B1 are correct to \pm 2 mm.

We calculated that the friction on the faces of the rough piles frozen into the ice over a length of 0.5 m would be sufficient to support the loads imposed on them and also that the probable rate of ablation would be about 0.4 m each year. Since a working life of three years was desirable, the minimum depth of pile frozen-in would have to be 1.7 m. We also installed a 0.5 m square sheet of plywood slotted onto each leg to reduce the ablation at the legs but in September 1980 we found that the ablation at the four load-bearing legs varied between 0.36 and 0.75 m while the protecting squares were stuck in their original position. The ice under the centre of

the hut had not ablated at the same rate and formed a domed hump under the building. Further measurements of the hut levels and the ablation will be taken in 1981, but the results indicate that no significant movement has occurred to date.

Table B-1

HEIGHT OF REFERENCE MARKS ON PILES ABOVE UNLOADED REFERENCE

Pile No.	Height above reference mark on unloaded pile. (cm).		
	11 April '80	23 Sept. '80	Difference
5	63.4	63.6	+0.2
6	64.0	64.4	+0.4
7	63.6	63.8	+0.2
8	64.2	64.4	+0.2

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13. ABSTRACT

A plug of multi-year sea ice lies in the entrance to Nansen Sound between Ellesmere and Axel Heiberg Islands. We discuss the history of the plug, give the results of observations made in 1980 and show that the plug is made up of sea ice of different ages and that it is still increasing in area. The present thickness of the ice in the oldest part of the plug averages about 6 metres.

KEY WORDS

Nansen Sound
 Sverdrup channel
 Ice plug
 Sea ice
 Ablation
 Morphology
 Thickness
 Ice profiles
 Temperature profiles
 Bathymetry

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